Observatorio Tecnológico del **Hidrógeno**

EXECUTIVE SUMMARY

Hydrogen as a vector for land mobility:

Technologies, market and challenges for its deployment

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SUPPORTED BY:

gasnam neutral transport

Hydrogen as a vector for land mobility:
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The decarbonisation of land mobility requires a **combination of technological solutions capable of adapting to very different operational realities**. In this context, green hydrogen is positioned as an energy vector with the capacity to play a significant role, especially in those segments where direct electrification using batteries faces technical, economic, or operational limitations. **Its greatest potential lies in applications associated** with short refuelling times and the need for high on-board autonomy, such as **long-distance heavy transport, buses, captive fleets, machinery and off-road applications**, where a favourable relationship is also required between the volume occupied on board and the energy stored by the system.

The **two main technological pathways** for its application are **fuel cells and internal combustion engines powered by hydrogen (H2-ICE)**. The former stand out for their high efficiency and absence of local emissions, while H_2-ICE offer a complementary alternative in those uses where mechanical robustness, lower initial cost or the use of existing platforms can facilitate faster implementation.

In addition, there are two decisive elements for its competitiveness: on-board storage and refuelling infrastructure. **High-pressure gaseous storage is currently the most mature solution, while liquid hydrogen is gaining interest in long-distance applications**, due to its higher energy density. In parallel, market development will depend on the ability to coordinate vehicles, supply, infrastructure and the cost of renewable hydrogen, in a context in which the greatest momentum is concentrated in trucks, buses, intensive fleets and other applications that are difficult to electrify.

This executive summary sets out the main conclusions of the report prepared by the Hydrogen Technology Observatory, and specifically by its members: **Bosch, CIDAUT (Foundation for Research and Development in Transport and Energy), CIRCE Foundation, CMT – Clean Mobility and Thermofluids at Universitat Politècnica de València, Enagás, Inetum, Linde and University of Barcelona**. The report is supported by **Gasnam-Neutral Transport.**

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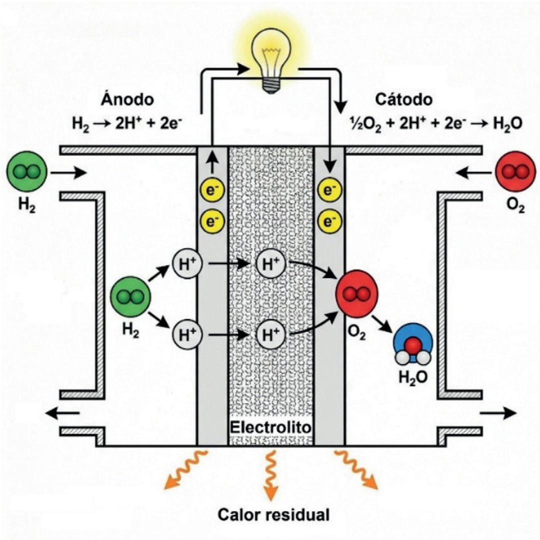
Fuel cells and hydrogen internal combustion engines (H_2-ICE), **predominant technologies for the use of hydrogen in automotive applications**

In land mobility, **the proton exchange membrane fuel cell (PEMFC)** is currently the dominant option. It enables effective **integration into electric propulsion architectures, with rapid start-up, good power density and operation without polluting emissions** at the point of use. Unlike combustion systems, the fuel cell does not require an intermediate thermal stage, which avoids thermodynamic limitations of conventional engines and supports greater energy efficiency.

Operating principle of a fuel cell



SOURCE: Own elaboration

In contrast to this pathway, **H_2-ICE** represent an alternative of great interest for certain applications. Although their efficiency is lower than fuel cells across much of the operating range and they may generate NO_X emissions (controllable through combustion and aftertreatment strategies), the ICE may achieve higher efficiency at high load levels. Their main advantage is industrial: **they make it possible to leverage part of the supply chains, manufacturing capacities and accumulated know-how in internal combustion engines**, reducing development times and part of the initial CAPEX.

Different typologies should be distinguished according to the ignition system and the original engine design:

- **According to the ignition system**

  - Spark-ignition engines (SIE):
    - Indirect, multi-point injection (PFI, Port Fuel Injection)
    - Direct injection (DI)
  - Compression-ignition engines (dual-fuel or H_2-CI)

- **According to the original engine design**

  - Dedicated hydrogen engines
  - Adapted or retrofitted engines

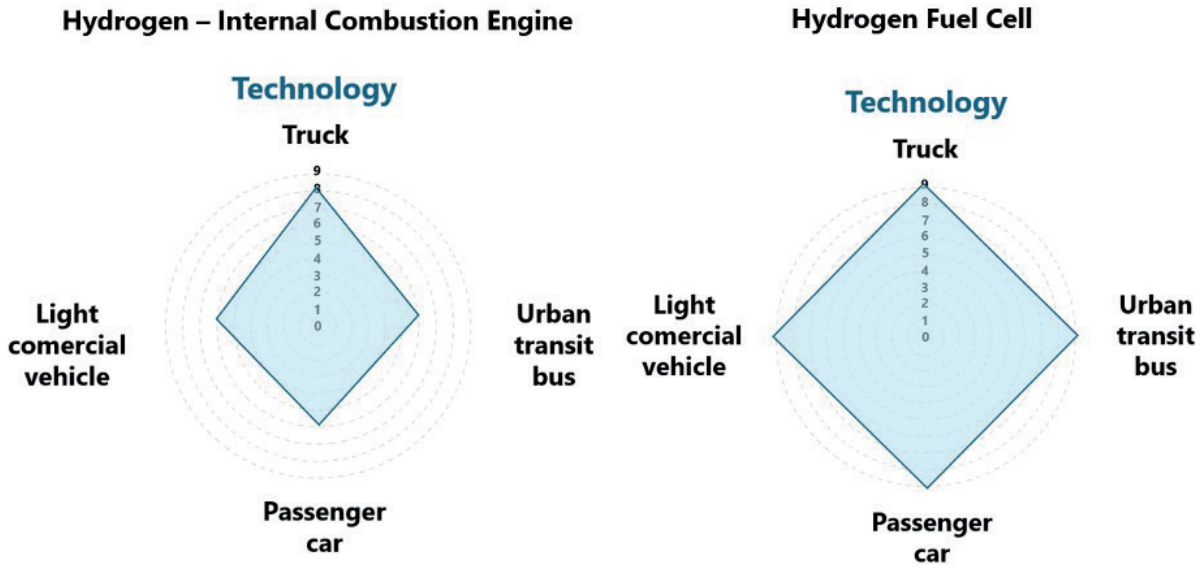
Comparison between propulsion technologies

Technology	Current status	TRL	Strengths	Weaknesses	Development trends
Fuel cells (FC, mainly PEMFC)	Commercial / fully tested in operational environments	9	• High efficiency • Zero local emissions • High power density • Good integration into electric propulsion system	• High initial cost • Use of platinum-based catalysts • High H_2 purity required • Competitiveness dependent on H_2 infrastructure and cost	• Consolidation in heavy transport and fleets • Evolution of materials and membranes • Development of alternatives such as AEM • Progressive reduction in the use of critical catalysts
Hydrogen internal combustion engines (H_2-ICE)	Early deployment / advanced commercial validation	Up to 8 (maximum observed in trucks)	• Use of existing platforms • Lower initial CAPEX • Mechanical robustness • Lower purity of H_2 required • Rapid implementation	• Lower efficiency than FC • Controllable but present NO_x emissions • Need for specific components	• Move towards dedicated H_2 designs • Improved combustion and emissions control • Focus on heavy trucks, machinery and off-road applications

SOURCE: Own elaboration with data as of April 2026

Regarding the **technology readiness levels** of propulsion technologies, **internal combustion engines show different levels depending on the vehicle, with truck engines at the highest level (TRL 8)**; while **fuel cell** technology shows a **uniform level of readiness** across the different types of vehicle analysed, standing at **TRL 9.**

Readiness level of the different technologies



SOURCE: International Energy Agency, 2026

Hydrogen storage systems in vehicles

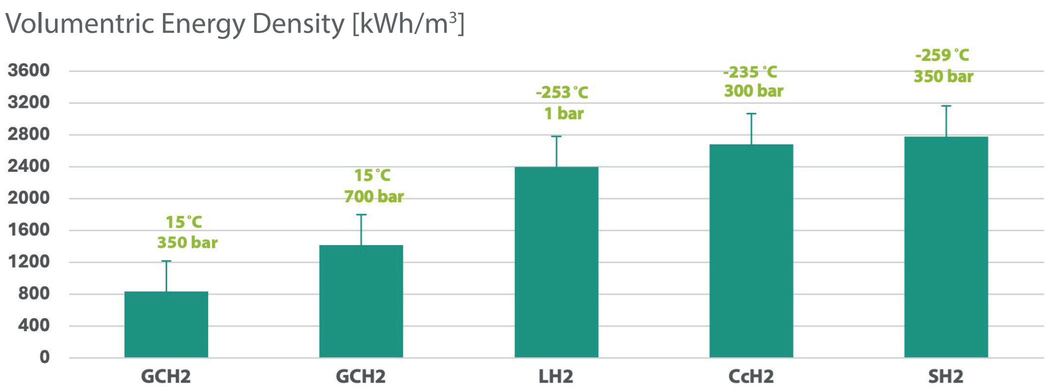
Unlike conventional liquid fuels, hydrogen has a **low volumetric energy density under ambient conditions**, which requires the use of specific technological solutions for its use in automotive applications. At present, **high-pressure gaseous storage** is the dominant and most commercially viable solution. In land mobility, the most common configurations are usually **350 bar**, especially in heavy and industrial transport, and **700 bar**, mainly in light vehicles and with growing interest for certain higher-autonomy applications.

The second major pathway is **liquid hydrogen (LH_2)**, which offers a clear advantage in terms of **volumetric energy density**, making it a particularly attractive alternative for long-distance heavy transport. However, this option requires cryogenic storage, with greater technical, operational and economic requirements.

There are **other emerging alternatives**, which have a lower degree of maturity:

- Cryo-compressed hydrogen storage
- Storage in solid materials

Energy density of the different forms of hydrogen storage



GCH2: Compressed hydrogen LH2: Liquefied hydrogen CcH2: Cryo-compressed hydrogen SH2: Slush hydrogen

SOURCE: Own elaboration

The success of hydrogen mobility does not depend solely on propulsion technology, but on the complete so-called 'energy pack'. In other words, on the coherent integration between hydrogen technology (FC or ICE), on-board storage and the refuelling system.

Comparison between hydrogen storage systems

Technology	Current status	TRL	Strengths	Weaknesses	Development trends
High-pressure gaseous hydrogen storage (cH2)	Commercial / dominant solution for road mobility	9	• Most widely deployed technology in hydrogen-powered vehicles. • Compatible with fast refuelling. • Widely used at pressures of 350 bar and 700 bar. • Established tank, regulation and safety architecture.	• Low volumetric energy density compared with liquid fuels. • Integration conditioned by safety, ventilation, structural resistance and crash management requirements..	• Optimisation of multi-cell designs. • Structural integration of tanks. • Evolution towards solutions offering greater range, especially at 700 bar.
Liquid hydrogen storage (LH2)	Emerging alternative for long-distance heavy mobility	9	• High volumetric energy density. • Enables the system volume to be reduced for the same stored energy. • Potential for greater ranges.	• High technical complexity. • Evaporation losses (boil-off). • Limited refuelling infrastructure.	• Improvement of cryogenic tanks and boil-off management. • Development of sub-cooled storage to increase density and reduce evaporation.
Cryo-compressed hydrogen storage (CcH2)	Technology under development / not yet widely deployed on the road	5	• Can achieve densities higher than liquid or compressed hydrogen separately. • Potential to increase the amount of hydrogen stored in a given volume.	• Increased complexity due to the combination of cryogenic and high-pressure requirements. • Lack of clear commercial maturity in land mobility	• Improvement of safety, insulation and vehicle integration. • Technical validation of pressurised cryogenic systems.
Storage in solid materials	Development phase / limited adoption in mobility	5	• Potential to store hydrogen more compactly and at lower pressure than gaseous systems.	• Relevant restrictions for widespread road deployment. • Potential penalties in mass, integration and charge/discharge dynamics.	• Development of metal hydrides, LOHC and adsorbent materials. • Reduction of system mass and improvement of absorption/ desorption kinetics.

SOURCE: Own elaboration with data as of April 2026

Hydrogen refuelling technologies

Hydrogen refuelling stations constitute the link that **connects hydrogen production and conditioning with its final use in the vehicle**. Their design directly influences refuelling time, supply capacity, system energy efficiency and the economic viability of fleets.

Three main configurations are distinguished:

- Compressed hydrogen stations supplied with compressed gas
- Compressed hydrogen stations supplied with liquid hydrogen
- Liquid hydrogen stations "on board"

Hydrogen refuelling station architectures according to fuel state

SOURCE: Linde, 2026

The technology of **compressed hydrogen stations supplied with compressed gas is the most widely implemented** in land mobility, both for light vehicles and for heavy-duty applications.

Stations can be supplied with hydrogen through on-site production (usually using an electrolyser) or through external supply.

In the case of external supply, according to the **characteristics of the supply** to the refuelling station, they can be divided into:

- Stations supplied with compressed gaseous hydrogen at different working pressures by means of banks of cylinders or semi-trailers.
- Stations where hydrogen is supplied by pipeline.
- Stations supplied with liquid hydrogen.

Hydrogen refuelling station in Barcelona

SOURCE: J.R. Morante

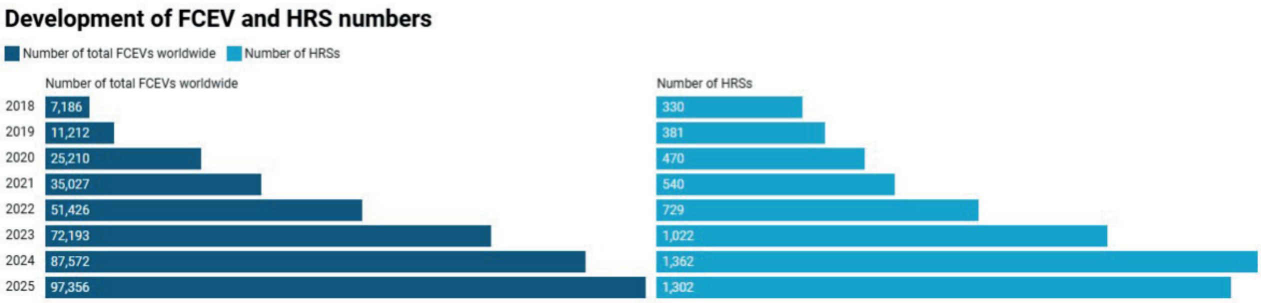
Global market for hydrogen vehicles and infrastructure

The market for hydrogen-based land mobility is in a transitional phase between advanced demonstration and early deployment, with highly uneven development across segments.

The greatest momentum is concentrated in **heavy transport**, **captive fleets** and **off-road applications**, where the operational advantages of hydrogen are clearest. This development is driven by three main factors: **regulatory pressure, institutional support and technological innovation.**

At global level, the fleet stands at around **100,000 fuel cell vehicles**, while the worldwide network exceeds **1,302 refuelling stations**.

Development of fuel cell vehicles and refuelling stations

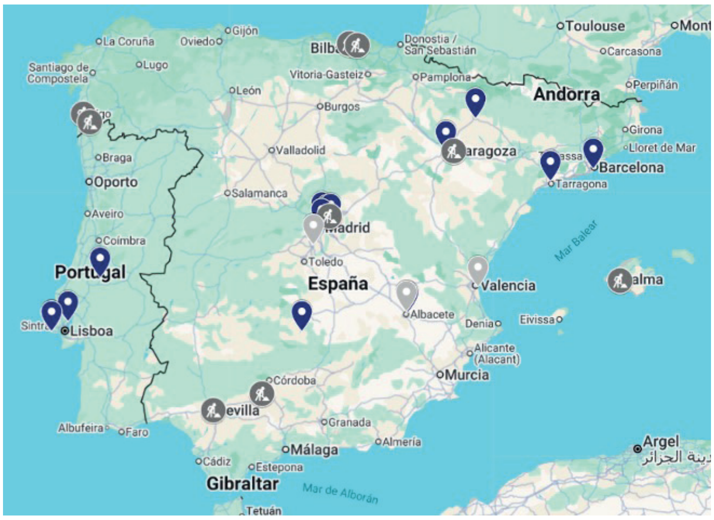


SOURCE: IEA Fuel Cells, Tracking Progress: Growth of Fuel Cell Electric Vehicles (FCEVs) and Hydrogen Infrastructure 2025

The market is highly geographically concentrated. **92% of vehicles** are located in **South Korea, China, the United States and Japan**, confirming that deployment remains dependent on environments with strong institutional and industrial support.

In **Spain**, by the end of 2025, **74 buses** and **45 light fuel cell vehicles** had been counted. In addition, there were **11 private refuelling points** and 3 refuelling points for trucks and material handling; and an estimated 6 new refuelling stations were under construction and due to open soon.

Hydrogen refuelling stations in Spain



SOURCE: Gasnam-Neutral Transport

In **light vehicles**, hydrogen maintains visibility, but its commercial maturity remains limited. Growth in the segment is highly conditioned by competition from battery electric vehicles, which have greater penetration, more infrastructure and more advanced economies of scale.

Even so, light hydrogen vehicles retain some interest in specific niches, such as taxis or intensive fleets, where **refuelling time** and **high operational availability** can provide an advantage over other technologies.

The greatest market potential is clearly shifting towards **heavy and freight transport**. In this area, hydrogen offers a better fit due to its high autonomy, rapid refuelling and high vehicle utilisation.

Market evolution can be understood across **three horizons**:

- In the **short term** (0–5 years): pilots and the first commercial fleets will dominate.
- In the **medium term** (5–15 years): industrial scaling is expected in trucks and buses.
- In the **long term** (>15 years): hydrogen will tend to specialise in high-energy-demand applications within a multimodal ecosystem.

Market evolution is already reflected in the **existence of specific hydrogen vehicle models** across various mobility segments. Examples of these models include the **Hyundai NEXO** and **Toyota Mirai** in light mobility, and the **Mercedes-Benz GenH2 Truck** and **Hyundai XCIENT Fuel Cell** as examples in heavy mobility.

European and Spanish regulatory framework

The regulatory framework is one of the main enablers for the deployment of hydrogen mobility. Its function is not only to organise the market, but also to **reduce uncertainty, set common objectives and create a stable environment** for investment in vehicles, infrastructure and the supply chain.

At European level, hydrogen mobility is integrated into the general decarbonisation strategy for **2030 and 2050**, aligned with the **'Fit for 55'** package and the objective of **climate neutrality in 2050.** In this framework, renewable and low-emission hydrogen is considered a key lever for decarbonising transport that is difficult to electrify using batteries alone.

One of the most relevant developments in the new European framework is **Directive (EU) 2024/1788** and **Regulation (EU) 2024/1789**, which establish common rules for the internal markets for renewable gas, natural gas and hydrogen. These rules are key to moving towards a more competitive, transparent and traceable market for renewable and low-emission hydrogen.

In the field of transport, **Alternative Fuels Infrastructure Regulation (AFIR) (EU) 2023/1804** is a central piece, as it introduces binding targets for the deployment of alternative fuels infrastructure on the **TEN-T** network (Trans-European Transport Network). Its importance is strategic because it reduces part of the regulatory risk and sends a clear signal to the market regarding the need to deploy hydrogen refuelling stations.

Alongside AFIR, **RED III** (EU Renewable Energy Directive) reinforces the role of hydrogen in transport by promoting renewable fuels of non-biological origin.

In Spain, the regulatory framework starts from the obligation to **transpose and apply** European legislation, especially AFIR and the new hydrogen market regulation. This implementation is structured mainly through the ministries responsible for transposing the European regulatory framework. RED III is currently in the process of being transposed to establish objectives for the mobility sector through a Royal Decree. Public consultation procedures have already been carried out and the opinion of the Council of State required prior to its approval is currently pending. The industry part will begin subsequently.

Although the main focus of the report is on land mobility, a specific annex on hydrogen railway applications is also included. Its interest is not so much due to the potential volume of energy demand from rail, which is expected to be more limited than that of other mobility segments, but rather to the technological, industrial and systemic synergies it can generate with the development of heavy road transport.

Overall, hydrogen-based land mobility is emerging as one of the **key levers for the decarbonisation of transport**, especially in those segments with higher energy demands. The **convergence of technology, industry, infrastructure, market and regulation** will be decisive in consolidating its deployment and maximising its contribution to more sustainable mobility.

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